NUTRIENT UPTAKE

Effects of Overseeding Cool-Season Annuals on Hay Yield and Nitrogen and Phosphorus Uptake by Tifton 44 Bermudagrass Fertilized with Swine Effluent

M. R. McLaughlin,* K. R. Sistani, T. E. Fairbrother, and D. E. Rowe

ABSTRACT

Use of Tifton 44 bermudagrass [*Cynodon dactylon* (L.) Pers.] in manure nutrient management is limited to summer haying. This study was done to determine how hay yield and nutrient uptake in a manure-fertilized Tifton 44 field were affected by fall overseeding and spring haying with berseem clover (*Trifolium alexandrinum* L.), crimson clover (*T. incarnatum* L.), annual ryegrass (*Lolium multiflorum* L.), and wheat (*Triticum aestivum* L.). Overseeding treatments were compared with a nonoverseeded control on Mantachie loam (fine, siliceous, acid, thermic Aeric Fluvaquents) receiving 168 kg P ha^{-1} in swine (*Sus scrofa domesticus*) effluent. Spring hay was cut April–June and summer hay July–October 2000–2002. Dry matter (DM) (4.4–5.5 Mg ha^{-1} yr^{-1}) and P uptake (12.2–17.1 kg ha^{-1} yr^{-1}) of spring berseem clover hay were higher than the control in 2 of 3 yr and higher than other treatments in 2002. Total DM and P uptake with berseem clover overseeding were 10% higher than the control. Final Mehlich-3 P soil levels (0–5 cm) tended to be lower in the berseem clover treatment than the control (65 vs. 81 mg kg^{-1}, respectively). Spring berseem clover hay was higher in N (94–122 kg ha^{-1} yr^{-1}) than the control each year and higher than other treatments in 2 of 3 yr. Summer Tifton 44 hay in the berseem clover treatment had more DM in 2002 and higher N uptake in 2001 and 2002 than other treatments. No treatment reduced Tifton 44 yield or nutrient uptake. Overseeding increased hay yield and nutrient uptake, and berseem clover was as good as or better than other treatments.

LAND APPLICATION of manures is often regulated according to soil P levels, or P index (Mallarino et al., 2002). Characterizations of crop plants and cropping systems for P uptake and long-term soil nutrient management have become more important (King et al., 1990; Rowe and Fairbrother, 2003). Pollution problems caused by P losses in runoff (Sharpley and Halvorson, 1994) can be reduced by increasing plant uptake of soil-available P. Utilization of manure nutrients to replace commercial fertilizers has focused research on forages (Adeli et al., 2002; Burns et al., 1990; Sims and Wolf, 1994). In the southeastern USA, bermudagrass responds well to the high levels of fertility found in swine effluent and consequently receives more effluent than other forages. Responses to effluent nutrient applications have been measured in DM yield and nutrient uptake for several bermudagrass varieties (Brink et al., 2003). Coastal bermudagrass receiving 670 kg N ha^{-1} and 153 kg P ha^{-1} from swine effluent removed an average of 382 kg N ha^{-1} yr^{-1} and 43 kg P ha^{-1} yr^{-1} (Burns et al., 1985). 'Alicia' bermudagrass responded to increasing levels of effluent by increasing DM yield and P uptake, up to an N equivalent of 448 kg ha^{-1} (Adeli and Varco, 2001), but higher levels of effluent N produced no further increases in DM. The efficiency of nutrient recovery in forage, as a percentage of nutrient applied in effluent, also declined with increasing rates of effluent fertilization for 'Russell' bermudagrass (Liu et al., 1997).

Nutrient uptake is a function of plant biomass and nutrient concentration, but both factors may vary due to differences in cultivars, weather, soil properties, and management practices (Robinson, 1996; Adeli et al., 2003; Brink et al., 2003; Rowe and Fairbrother, 2003; McLaughlin et al., 2004). Harvesting of all types of bermudagrass hays, however, is restricted to warm summer months. Annual forage DM production and nutrient uptake in bermudagrass-based systems may be improved by effectively extending the forage production season. Double-cropping warm-season bermudagrass with cool-season annual forages, which grow during the fall, winter, and spring when bermudagrass is dormant, has been proposed for manure nutrient management systems in the southeastern USA (McLaughlin et al., 2001; Brink et al., 2003; Rowe and Fairbrother, 2003).

This study examined the effects of overseeding cool-season annual forages on Tifton 44 bermudagrass harvested for hay in a field fertilized with swine effluent. The objectives were to determine total annual N and P removal in hay harvested from the overseeding treatment plots and to compare overseeding treatments in late-spring harvests of the cool-season forage hays and in summer harvests of the Tifton 44 bermudagrass hay. The goal of the research was to identify overseeding treatments that extend nutrient removal in the hay field beyond the summer growing season and subsequently increase total annual hay production and N and P utilization.

MATERIALS AND METHODS

The study was conducted on a private farm near Ackerman in northeastern Choctaw County, Mississippi, USA (33°30′ N, 88°16′ W). Experimental plots were located in a bermudagrass

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Abbreviations: DM, dry matter.

Table 1. Initial nutrient levels of Mantachie soil in the experimental plot area near Ackerman MS, 1999.

Depth	pH	Mehlich-3 P	NO_3	Ca	Mg	K	Cu	Fe	Mn	Zn
cm	[H+]	mg/kg		g/kg			mg/kg			
				Inside fertilized area						
0–5	7.1	81.7	267.1	0.7	0.7	0.1	0.6	353.1	203.7	1.4
5–10	7.6	6.1	101.1	0.5	0.6	0.1	0.8	334.2	204.0	0.3
10–20	7.3	0.0	88.5	0.4	0.4	0.0	1.0	218.5	270.5	0.0
				Outside fertilized area						
0–5	6.5	0.8	16.8	0.1	0.4	0.1	0.7	257.2	168.3	0.2
5–10	6.5	0.0	15.4	0.1	0.4	0.1	0.8	302.6	180.4	0.0
10–20	6.1	0.0	16.6	0.0	0.3	0.0	0.7	225.0	192.5	0.0

hay field that received applications of swine lagoon effluent. Plots were on a Mantachie soil (fine-loamy, siliceous, acid, thermic Aeric Fluvaquents) with 0 to 2% slope. The field received anaerobic lagoon effluent and produced summer hay from a well-established stand of Tifton 44 bermudagrass. The Tifton 44 had been established from sprigs in 1996, and the field had been treated with effluent from June through October each year beginning in 1996. Overhead irrigation with a pressurized spray gun and retracting reel system was used to apply effluent. Timing and amounts of effluent applications were determined by the farm manager. Initial soil test nutrient levels were measured in the plot area of the hay field at the start of the study in October 1999 (Table 1). Final soil test nutrient levels were determined from soil samples collected in each plot in October 2002. Selected soil chemical characteristics, including P concentration, were determined for each sample using Mehlich-3 extractant (Mehlich, 1984). Soil NO_3 concentrations were determined following methods described by Mulvaney (1996). Rainfall records in the vicinity of the hay field were obtained from the National Weather Service (Fig. 1). Although rainfall during the first year of the study was below normal, timely effluent applications in September 1999 (0.88 ha cm) and June–September 2000 (6.15 ha cm) served to minimize the effects of the drought. Effluent applications to the plots were collected and measured using four meteorological rain gauges, one placed to collect effluent 20 cm above the soil surface in each block of the experiment. Volumes of four replicate samples were recorded immediately after each effluent application, and the samples were combined and frozen for subsequent nutrient analysis, as described by Brink et al. (2003). Effluent amounts and total N and P applied in effluent are shown in Table 2. Application rates to the experimental plots varied among years at the discretion of the farm manager. There was no attempt to account for variability in amounts and nutrient concentrations in the effluent; however, differences in rainfall, competing fertilization requirements in other hay fields, and the age and nutritional requirements of the pigs, were all contributing factors.

Experimental plots were 2 by 5 m and were separated and surrounded by 1-m alleys and borders. Overseeding treatments consisting of four cool-season annual forages and a nonoverseeded control were arranged in a randomized complete block design replicated four times. Overseeding treatments were repeated in the same plots each year. Cool-season annuals were berseem clover (‘Bigbee’), crimson clover (‘Tibbee’), annual ryegrass (‘Gulf’), and winter wheat (‘Terral TV8768’). The clovers (22 kg seed ha^{-1}) and ryegrass (34 kg seed ha^{-1}) were seeded using an ALMACO drill seeder, and wheat (84 kg seed ha^{-1}) was seeded using a Tye drill. All annuals were drilled in rows 18 cm apart. Plots were prepared for planting by clipping the bermudagrass at a cutting height of 2.5 cm. Seeding was done on 16 Nov. 1999, 12 Oct. 2000, and 10 Oct. 2001. A volunteer stand of little barley (*Hordeum pusillum* Nutt.) in the plot area was controlled in 1999 by application of Poast Plus herbicide (13 mL L^{-1} applied 8 Dec. with a backpack sprayer) in all except ryegrass and wheat plots. Little barley made lush growth in the ryegrass and wheat plots in early spring of 2000 but was prevented from reseeding by

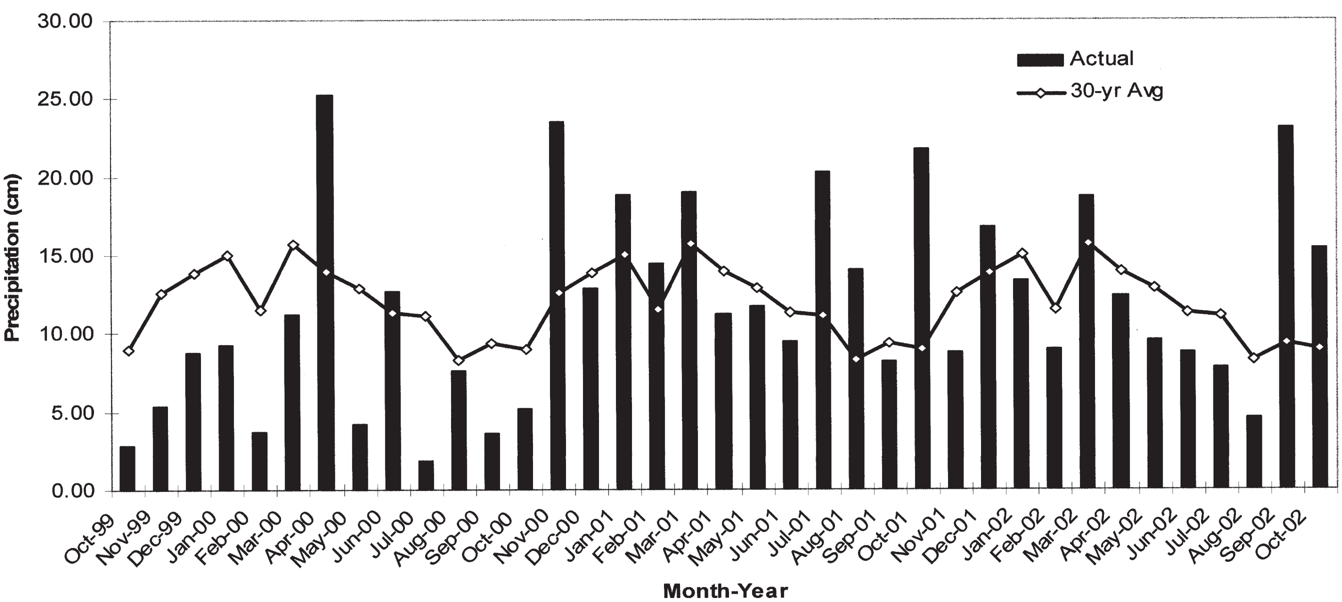

Fig. 1. Actual and 30-yr mean monthly precipitation during the course of the experiment. Data were recorded by the National Weather Service in the vicinity of the experimental plots.

Table 2. Total N and P applied in effluent.

Year	Effluent applied	Nutrients		
		N	P	N/P
	— ha cm —	— kg ha^{-1} —		
2000	7.03	598	78	7.7
2001	5.08	361	69	5.2
2002	1.8	138	21	6.6
3-yr total	13.91	1097	168	6.5

early harvest of the experimental plots (Fig. 2) and posed no problem in later years.

Plots were harvested for hay at 4- to 6-wk intervals beginning in late April (Fig. 2), except for 2000 when the first harvest was made in late March, as described above. All harvesting was done using a sickle-bar mower. First harvests in spring were made at a cutting height of 10 cm to permit regrowth of cool-season annuals. Subsequent harvests were at a cutting height of 5 cm. Fresh weight yields were recorded for 1- by 5-m swaths cut through the center of each plot. Forage samples of 1-kg each were collected in muslin bags, dried at 65°C for 72 h, weighed to determine DM yields for each plot and harvest, and ground to pass a 1-mm screen in a Wiley mill and then in a Cyclotec mill to pass a 0.5-mm screen.

Subsamples of 50 g of each ground sample were stored at room temperature in sealed plastic amber-color vials for subsequent nutrient analysis. Total N concentration was determined by the macro-Kjeldahl procedure (Bremner, 1996), and P concentrations were measured using an inductively coupled argon plasma emission spectrophotometer following dry ashing, acid resuspension, and filtration methods described by Brink et al. (2001). Nutrient uptake was calculated as the product of the nutrient concentration and DM yield for each plot and harvest. The total N content of clover hays was calculated in like manner, without distinction of legume-fixed atmospheric N from that acquired through effluent or soil.

Overseeding treatment effects on DM yield and nutrient content of cool-season annual spring hay were tested using summed data from Harvests 1 and 2 (Fig. 2). Treatment effects on DM yield and nutrient uptake of Tifton 44 bermudagrass hay were tested using cumulative data summed from Harvests 3 to 5 (Fig. 2). Cumulative DM yield and uptake or content were also calculated for sequential harvests within each year. Cumulative DM yield data were analyzed using SAS mixed model and general linear models procedures on a balanced and complete data set (Littell et al., 1996; SAS Inst., 1990). Year × harvest, year × treatment, and year × harvest × treatment interactions in analysis of total annual DM yield were significant ($P < 0.001$), so data were separated by year for further analysis. Treatment means were compared by Fisher's protected LSD ($P \leq 0.05$).

RESULTS AND DISCUSSION

Dry Matter Yield

Bermudagrass came out of dormancy earlier in control plots than in overseeded plots, probably due to less ground cover and the fact that Tifton 44 starts growth earlier in the spring than most bermudagrass varieties (Burton and Monson, 1978). Control plots yielded a mixture of winter annual weeds and bermudagrass in the first harvest and predominantly bermudagrass in the second harvest each year. Cool-season annual treatment plots yielded predominantly cool-season annual hay in the first harvest and a mixture of cool-season annual and bermudagrass in the second harvest. Bigbee berseem clover matured later than Tibbee crimson clover (Knight, 1972, 1985), which bloomed in mid-April and produced little regrowth after the first harvest. Bigbee produced forage in late May and early June, later than most other annual clovers (Knight, 1985). By July, at the time of the third harvest in the present study, all treatment plots were virtual bermudagrass monocultures. Mean cumulative DM yields through five successive harvests in 2000 were higher in ryegrass and wheat treatment plots (both yielded 15.4 Mg DM ha^{-1}) than in other treatments (12.2 Mg DM ha^{-1}for berseem and crimson; 11.3 Mg DM ha^{-1} for the control), but the differences were attributed to lush growth of little barley in the first harvest (Fig. 3). Herbicide treatment eliminated the volunteer barley in clover treatment and control plots but could not be used in the ryegrass and wheat plots. This proba-

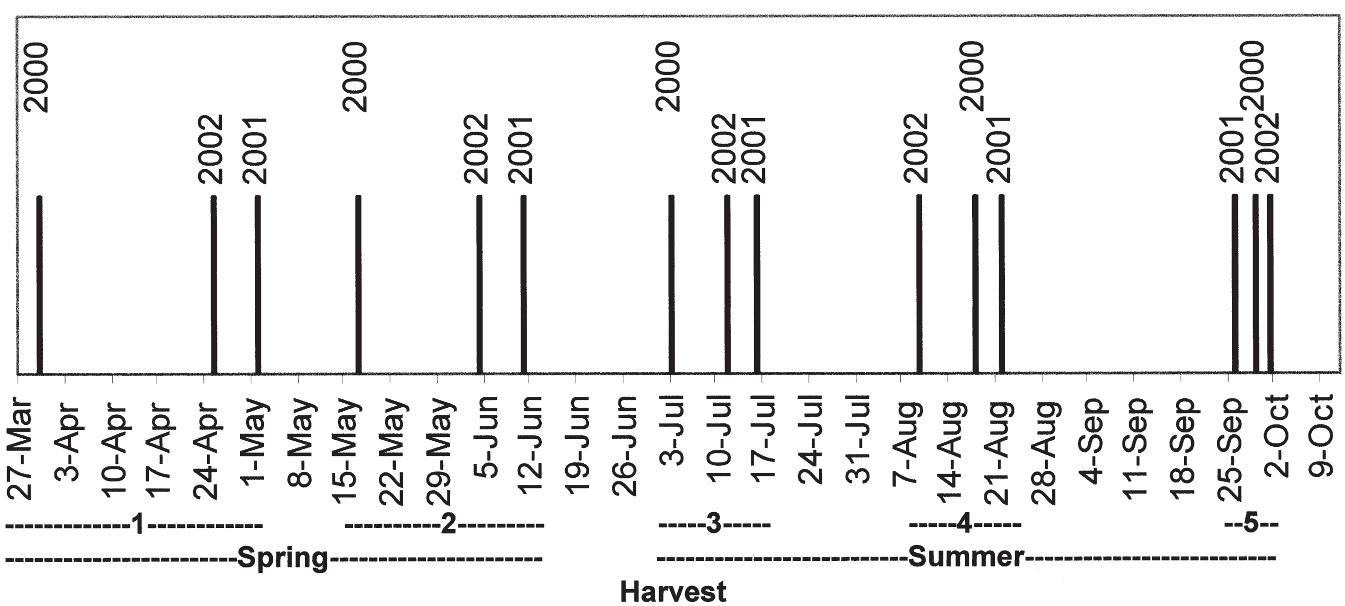

Fig. 2. Dates of five annual harvests of Tifton 44 bermudagrass plots with combinations of 1 to 2 and 3 to 5 used in spring vs. summer comparisons.

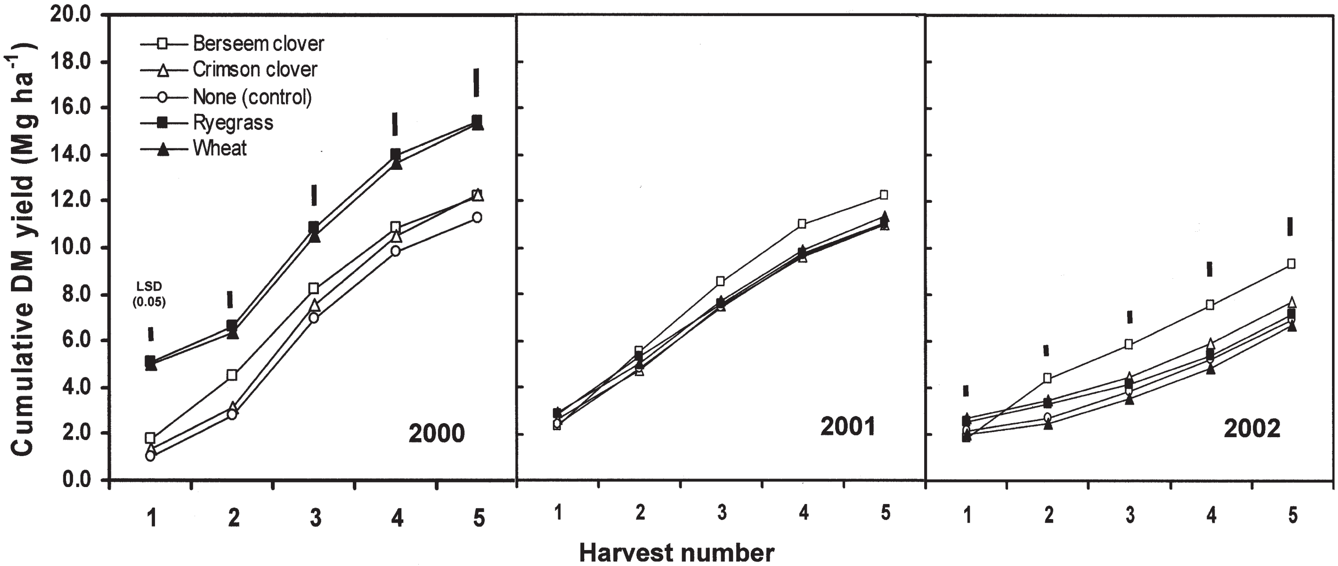

Fig. 3. Cumulative dry matter (DM) yield for each of five winter annual overseeding treatments through five harvests annually in Tifton 44 bermudagrass plots.

bly contributed toward the interactions of year, treatment, and harvest observed in initial analysis of the combined data. In 2001, mean total cumulative DM yield (11.3 Mg DM ha^{-1}) after five harvests did not differ ($P = 0.07$) between overseeding treatments but showed a trend toward increased DM yield in the berseem clover treatment. In 2002 mean total cumulative yield in berseem clover treatment plots (9.3 Mg DM ha^{-1}) was higher than other treatments, which were 6.7, 6.9, 7.1, and 7.7 Mg DM ha^{-1} for the wheat, control, ryegrass and crimson clover treatments, respectively (Fig. 3). Despite potential confounding by variable growing conditions, most notably rainfall, total DM yield response to total applied N across years in Tifton 44 control plots was linear (Mg DM ha^{-1} = 0.0094 × kg N ha^{-1} + 2.8769, $R^2 = 0.99$). This observation and the fact that summer bermudagrass DM yield in the berseem clover treatment in 2002 was higher than the control (Fig. 4) when effluent N applications were lowest (Table 2) suggests possible increased N available from that fixed by the berseem clover. Crimson and berseem clover have been reported to fix from 51 to 188 kg N ha^{-1}, depending on the experimental conditions (Torbert et al., 1996; Stout et al., 1997; Karpenstein-Machan and Stuelpnagel, 2000; Mueller and Thorup-Kristensen, 2001). The trend line for mean cumulative DM yield of the crimson clover treatment in 2002 was consistent with this hypothesis although the crimson and control treatments were not statistically different (LSD = 0.8 Mg DM ha^{-1}) (Fig. 3). This possible clover-fixed N effect is also suggested by the 2001 berseem treatment data (Fig. 3) when effluent-applied N levels were midrange between the high level of 2000 and low level of 2002 (Table 2). This effect was not apparent in 2000 (Fig. 3) when effluent-applied N was highest (Table 2). High soil N or supplemental N fertilization are known to suppress N fixation in clovers (Blue and Carlisle, 1985). No other effects on DM yield were

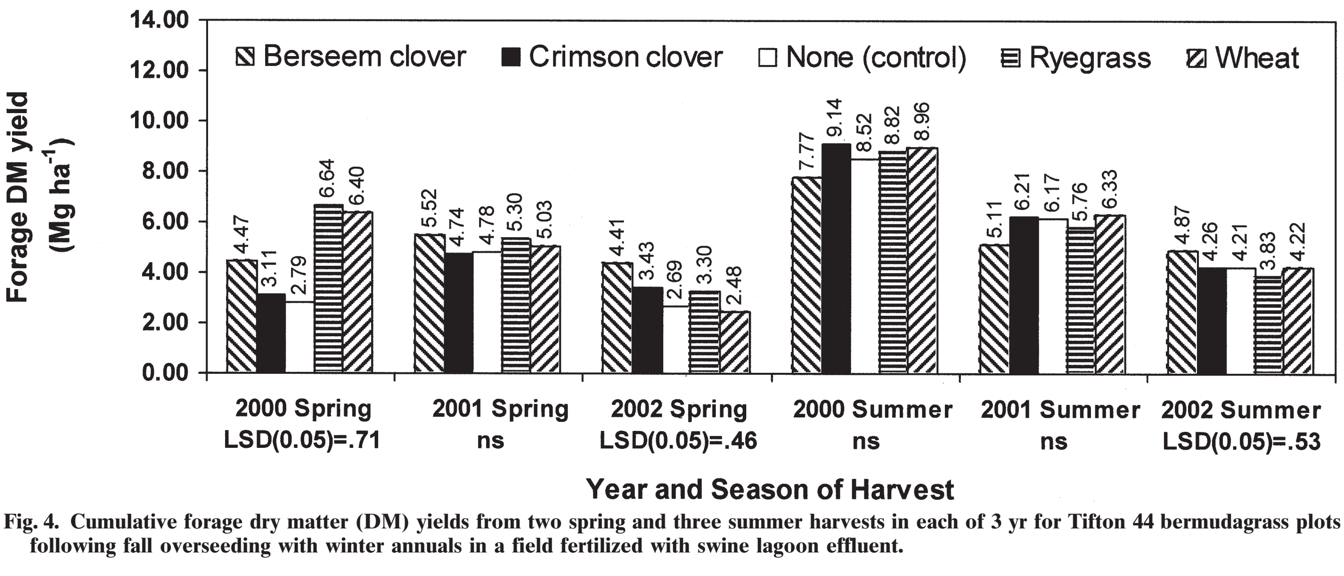

Fig. 4. Cumulative forage dry matter (DM) yields from two spring and three summer harvests in each of 3 yr for Tifton 44 bermudagrass plots following fall overseeding with winter annuals in a field fertilized with swine lagoon effluent.

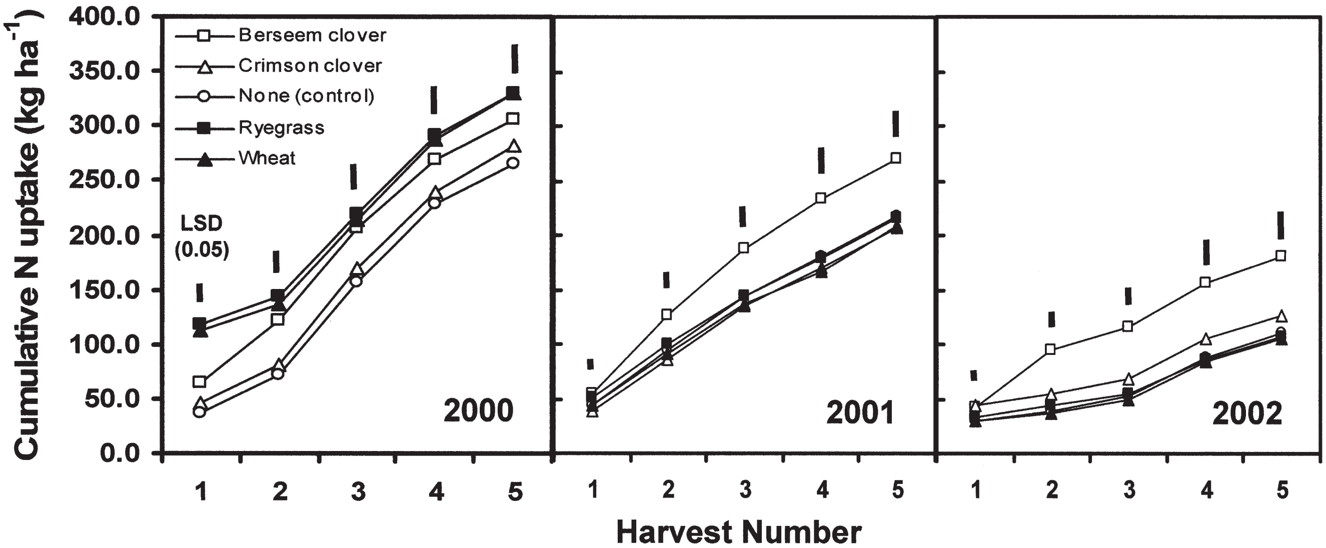

Fig. 5. Cumulative N uptake for each of five winter annual overseeding treatments through five harvests annually in Tifton 44 bermudagrass plots (ns = not significant in ANOVA *F* test).

detected, indicating no adverse effects of the cool-season annual species on the warm-season perennial grass.

Nitrogen and Phosphorus

Mean total annual cumulative removal of N was higher in hays from the berseem clover treatment (180–306 kg ha^{-1} yr^{-1}) than in the control (110–266 kg ha^{-1} yr^{-1}) in all 3 yr and higher than all other treatments, which were not significantly different in 2001 (mean = 213 kg ha^{-1}) and 2002 (mean = 113 kg ha^{-1}) (Fig. 5). In 2000, N uptake was higher in ryegrass and wheat treatments, but the effect was attributed to the first harvest when little barley predominated in these treatment plots. In 2001 and 2002, after the barley was eliminated in all plots, mean cumulative DM yields in ryegrass and wheat treatments were not different from the control. Removal of N was greater in berseem clover than in the control treatment in spring harvests all 3 yr and in the summer harvest in 2002 (Fig. 6). These results suggest that the berseem clover provided additional plant-available N, which was utilized by the summer grass, and that this effect was most significant when effluent-applied N levels were lowest.

Mean cumulative uptake of P was higher in the berseem clover treatment than in the control in 2000 (36 vs. 32 kg ha^{-1}, respectively, LSD 0.05 = 2.5) and 2002 (26 vs. 21 kg ha^{-1}, respectively, LSD 0.05 = 2.8) but not in 2001 (Fig. 7). Uptake of P in berseem clover spring hay in the present study (12.2–17.5 kg ha^{-1} yr^{-1}) was less than that (27.1 kg ha^{-1} yr^{-1}) reported for berseem clover overseeded in common bermudagrass on a Prentiss loam fertilized with swine effluent, which added P at 110 kg ha^{-1} yr^{-1} (Rowe and Fairbrother, 2003). Total uptake of P in the berseem clover treatment during the present 3-yr study was 92.3 kg ha^{-1} compared with 83.7 kg ha^{-1} in the control. These amounts were 55 and 50%, respectively, of the total P applied in effluent and are considerably higher than P recovery rates

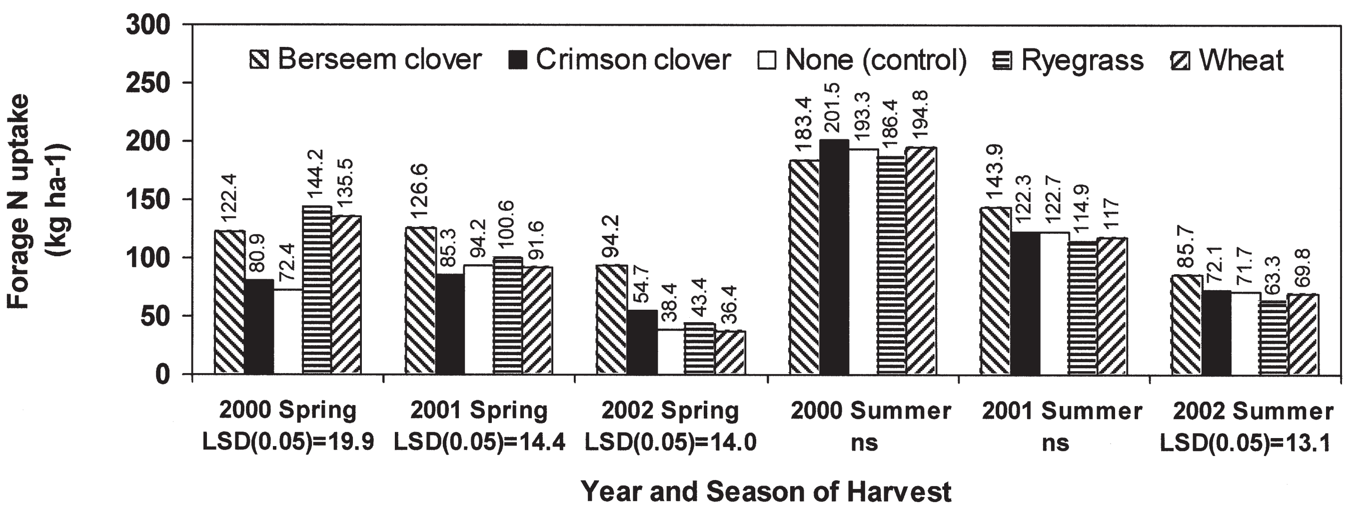

Fig. 6. Cumulative forage N uptake from two spring and three summer harvests in each of 3 yr for Tifton 44 bermudagrass plots following fall overseeding with winter annuals in a field fertilized with swine lagoon effluent (ns = not significant in ANOVA *F* test).

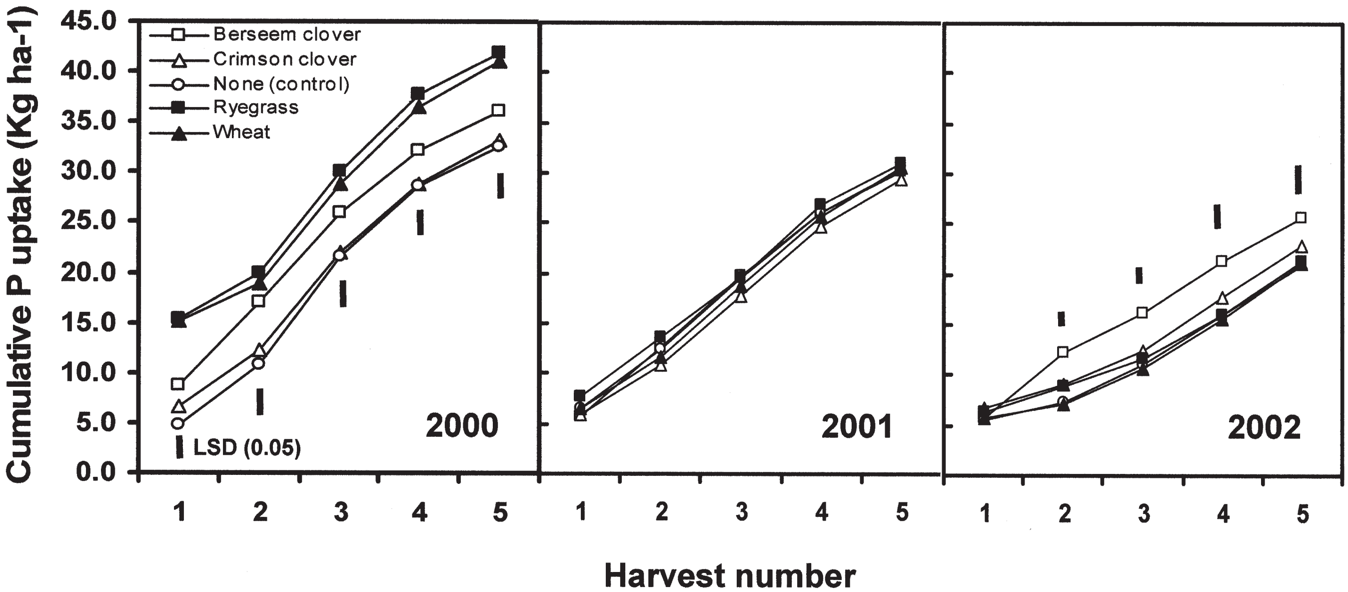

Fig. 7. Cumulative P uptake for each of five winter annual overseeding treatments through five harvests annually in Tifton 44 bermudagrass plots.

reported by Johnson et al. (2004) for overseeded (annual ryegrass) Coastal bermudagrass fertilized with poultry litter and dairy wastewater and by Sanderson and Jones (1997) for overseeded bermudagrass fertilized with dairy manure. The P recovery rate of the control in the present study was, however, considerably lower than that derived from Brink et al. (2003), who reported P uptake of 39 kg ha^{-1} yr^{-1} for Tifton 44 grown on an Atwood silt loam fertilized with swine effluent, which added P at 38 kg ha^{-1} yr^{-1}. The P uptake was higher in ryegrass and wheat treatments than in other treatments in 2000 of the present study, but as with DM yield and N uptake, these differences were attributed to little barley in the first harvest in 2000 and were not observed in 2001 or 2002 (Fig. 7). Unlike the N uptake results, where increases in berseem N removal appeared to extend from spring into summer harvests (Fig. 6), increased P uptake observed in spring harvests of berseem clover in 2000 and 2002 did not extend into summer grass harvests (Fig. 8). No treatment differences occurred among overseeding treatment means for summer P uptake (means = 21.1, 18.1, and 13.5 kg ha^{-1} in 2000, 2001, and 2002, respectively).

Residual Soil Nitrate and Mehlich-3 Phosphorus

Soil test NO_3 levels at the end of the study showed marked reductions compared with levels inside the effluent-treated area of the hay field at the beginning of the study (Fig. 9). Levels in the treatment plots after the study, although not compared statistically, were not appreciably higher than initial levels in soil outside the effluent-treated area. No differences in soil test NO_3 levels were found between treatments at any of the soil core depths tested. These results are consistent with low effluent N application in 2002.

Mehlich-3 soil test P concentrations at the end of the study showed no differences within the 0- to 5- and 5- to 10-cm cores among berseem clover, crimson clover, control, and ryegrass treatments, but concentrations follow-

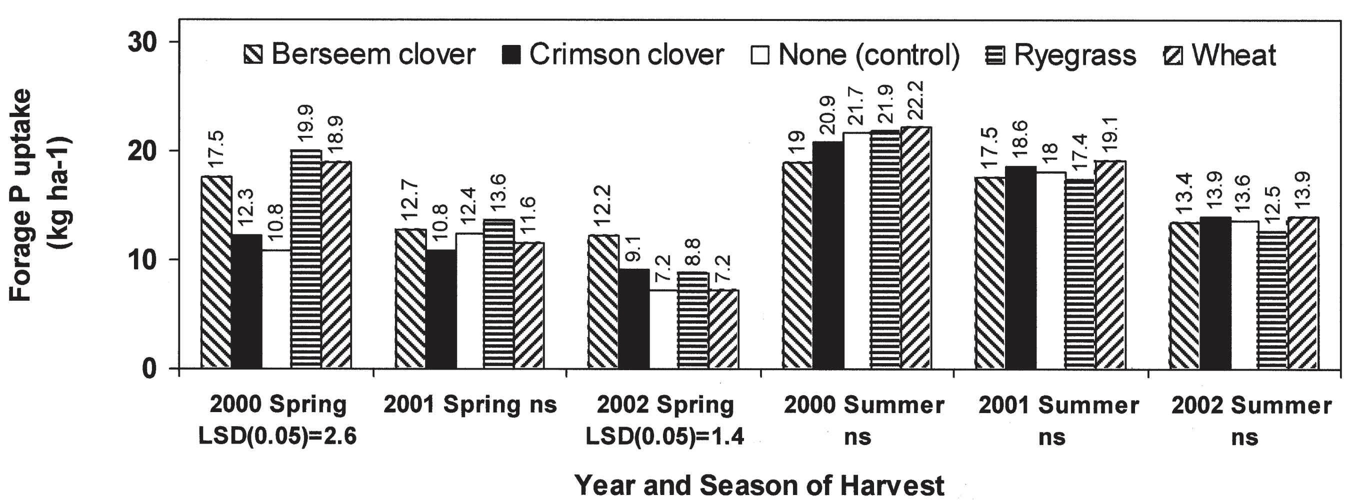

Fig. 8. Cumulative forage P uptake from two spring and three summer harvests in each of 3 yr for Tifton 44 bermudagrass plots following fall overseeding with winter annuals in a field fertilized with swine lagoon effluent (ns = not significant in ANOVA *F* test).

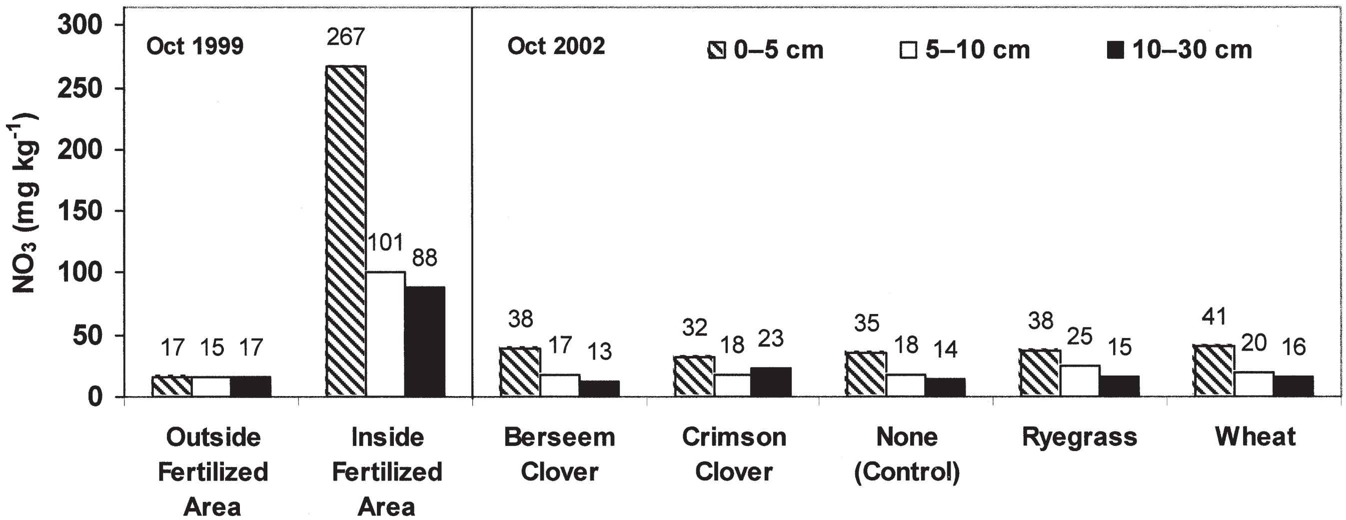

Fig. 9. Soil test NO_3 levels before (Oct. 1999) and after (Oct. 2002) the 3-yr overseeding experiment. Differences between treatments were not significant when compared within sampling depths.

ing wheat were inexplicably higher than other treatments (Fig. 10). Although untested, one hypothesis for this apparent increase in Mehlich-3 P is that P sequestered within wheat roots and stubble in the present study was released into the soil at a different rate (more slowly) than that from other species. This apparent difference was not observed in a parallel study containing wheat overseeded in common bermudagrass on a Prentiss sandy loam (McLaughlin et al., 2005), which suggests that for the hypothesis to be correct, the soil type and bermudagrass variety may be important contributing factors. No treatment differences in Mehlich-3 P concentrations were found in 10- to 30-cm cores. All treatments showed increases in Mehlich-3 P concentrations in 5- to 10- and 10- to 30-cm cores (Fig. 10), suggesting movement of P deeper into the soil profile during the course of the study. Additional research is needed to document total soil P amounts and movement before reaching conclusions concerning overseeding treatment effects on total P balance in this waste management system.

CONCLUSIONS

Growth of Tifton 44 bermudagrass was not adversely affected by overseeding with any of the cool-season annual forages tested. Overseeding with berseem clover increased total DM hay yield compared with the non-overseeded control by 8% in 2000 when effluent-applied N was highest (598 kg ha^{-1}), 11% in 2001 when effluent-applied N was 361 kg ha^{-1}, and 35% in 2002 when effluent-applied N was lowest (138 kg ha^{-1}). These increases in cumulative annual DM yield were due to

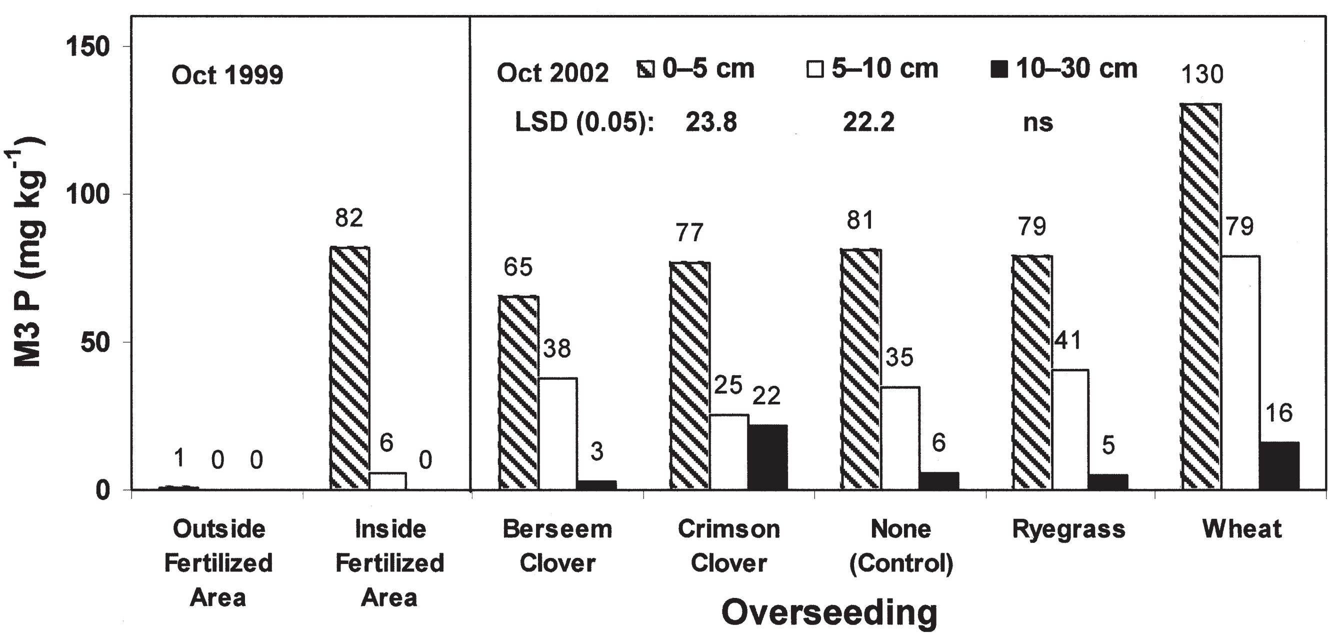

Fig. 10. Mehlich-3 soil test P levels before (Oct. 1999) and after (Oct. 2002) the 3-yr overseeding experiment. LSD values pertain to treatment differences within the respective sampling depths (ns = not significant in ANOVA *F* test).

increases in spring berseem clover hay yield in 2000 and to increased spring and summer hay yields in 2002. Increased summer bermudagrass DM yield in the berseem clover treatment in 2002 may have been due to a N fixation effect that was precluded or masked by higher effluent-applied N in 2000 and 2001. Total summer Tifton 44 DM yield in nonoverseeded control plots showed a linear response to total annual effluent N. Overseeding with berseem clover increased total annual N removal compared with the nonoverseeded control by 15% in 2000, 25% in 2001, and 63% in 2002. The increased N removal was due to increases in N content in spring-harvested berseem clover hay in all years of the study and to increased N uptake in summer-harvested Tifton 44 bermudagrass hay in 2002. Overseeding with berseem clover increased total P uptake over the nonoverseeded control by 11% in 2000 and 23% in 2002, with no differences in 2001. Increased P uptake in 2000 and 2002 was attributed to the spring berseem clover hay harvest. Overseeding did not affect summer P uptake in Tifton 44 bermudagrass. Overseeding Tifton 44 bermudagrass with berseem clover provides farm managers with a valuable tool for improving P management and hay production in swine effluent application fields in the southeastern USA.

REFERENCES

Adeli, A., and J.J. Varco. 2001. Swine effluent as a source of nitrogen and phosphorus for summer forage grasses. Agron. J. 93:1174–1181.

Adeli, A., J.J. Varco, S.M. Mostafa, D.E. Rowe, and M.F. Bala. 2002. Comparability of anaerobic swine lagoon effluent to commercial fertilizer on soil nutrient dynamics. Commun. Soil Sci. Plant Anal. 33:3779–3795.

Adeli, A., J.J. Varco, and D.E. Rowe. 2003. Swine effluent irrigation rate and timing effects on bermudagrass growth, nitrogen and phosphorous utilization, and residual soil nitrogen. J. Environ. Qual. 32:681–686.

Blue, W.G., and V.W. Carlisle. 1985. Soils for clovers. p. 185–204. *In* N.L. Taylor (ed.) Clover science and technology. Agron. Monogr. 25. ASA, CSSA, and SSSA, Madison, WI.

Bremner, J.M. 1996. Nitrogen–total. p. 1085–1122. *In* D.L. Sparks et al. (ed.) Methods of soil analysis. Part 3. Chemical methods. SSSA Book Ser. 5. SSSA and ASA, Madison, WI.

Brink, G.E., G.A. Pederson, K.R. Sistani, and T.E. Fairbrother. 2001. Uptake of selected nutrients by temperate grasses and legumes. Agron. J. 93:887–890.

Brink, G.E., D.E. Rowe, K.R. Sistani, and A. Adeli. 2003. Bermudagrass cultivar response to swine effluent application. Agron. J. 95:597–601.

Burns, J.C., L.D. King, and P.W. Westerman. 1990. Long-term swine lagoon effluent applications on 'Coastal' bermudagrass: I. Yield, quality, and element removal. J. Environ. Qual. 19:749–756.

Burns, J.C., P.W. Westerman, L.D. King, G.A. Cummings, M.R. Overcash, and L. Goode. 1985. Swine lagoon effluent applied to 'Coastal' bermudagrass: I. Forage yield, quality, and element removal. J. Environ. Qual. 14:9–14.

Burton, G.W., and W.G. Monson. 1978. Registration of Tifton 44 bermudagrass. Crop Sci. 18:911.

Johnson, A.F., D.M. Vietor, F.M. Rouquette, Jr., and V.A. Haby. 2004. Fate of phosphorus in dairy wastewater and poultry litter applied on grassland. J. Environ. Qual. 33:735–739.

Karpenstein-Machan, M., and R. Stuelpnagel. 2000. Biomass yield and nitrogen fixation of legumes monocropped and intercropped with rye and rotation effects on a subsequent maize crop. Plant Soil 218:215–232.

King, L.D., J.C. Burns, and P.W. Westerman. 1990. Long-term swine effluent applications on 'Coastal' bermudagrass: II. Effect on nutrient accumulation in soil. J. Environ. Qual. 19:756–760.

Knight, W.E. 1972. Registration of Tibbee crimson clover. Crop Sci. 12:126.

Knight, W.E. 1985. Registration of 'Bigbee' berseem clover. Crop Sci. 25:571–572.

Littell, R.C., G.A. Milliken, W.W. Stroup, and R.D. Wolfinger. 1996. SAS system for mixed models. SAS Institute, Inc., Cary, NC.

Liu, F., C.C. Mitchell, J.W. Odom, D.T. Hill, and E.W. Rochester. 1997. Swine lagoon effluent disposal by overland flow: Effects on forage production and uptake of nitrogen and phosphorus. Agron. J. 89:900–904.

Mallarino, A.P., B.M. Stewart, J.L. Baker, J.D. Downing, and J.E. Sawyer. 2002. Phosphorus indexing for cropland: Overview and basic concepts of the Iowa phosphorus index. J. Soil Water Conserv. 57:440–447.

McLaughlin, M.R., T.E. Fairbrother, and D.E. Rowe. 2001. Clover increases phosphorus removal in a bermudagrass hay system irrigated with swine lagoon effluent. p. 724–727. *In* Proc. Int. Symp. on Anim. Prod. and Environ. Issues., Research Triangle Park, NC. 3–5 Oct. 2001. Vol. 2. North Carolina State Univ., Raleigh.

McLaughlin, M.R., T.E. Fairbrother, and D.E. Rowe. 2004. Nutrient uptake by warm-season perennial grasses in a swine effluent spray field. Agron. J. 96:484–493.

McLaughlin, M.R., K.R. Sistani, T.E. Fairbrother, and D.E. Rowe. 2005. Overseeding common bermudagrass with cool-season annuals to increase yield and nitrogen and phosphorus uptake in a hay field fertilized with swine effluent. Agron. J. 97:487–493 (this issue).

Mehlich, A. 1984. Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Commun. Soil Sci. Plant Anal. 15:1409–1416.

Mueller, T., and K. Thorup-Kristensen. 2001. N-fixation of selected green manure plants in an organic rotation. Biol. Agric. Hortic. 18:345–363.

Mulvaney, R.L. 1996. Nitrogen—inorganic forms. p. 1123–1131. *In* D.L. Sparks et al (ed.) Methods of soil analysis. Part 3. Chemical methods. SSSA Book Ser. 5. SSSA and ASA, Madison, WI.

Robinson, D.L. 1996. Fertilization and nutrient utilization in harvested forage systems—southern forage crops. p. 65–92. *In* R.E. Joost and C.A. Roberts (ed.) Nutrient cycling in forage systems. Proc. Symp., Columbia, MO. 7–8 Mar. 1996. Potash and Phosphate Inst., Manhattan, KS.

Rowe, D.E., and T.E. Fairbrother. 2003. Harvesting winter forages to extract manure soil nutrients. Agron. J. 95:1209–1212.

Sanderson, M.A., and R.M. Jones. 1997. Forage yields, nutrient uptake, soil chemical changes, and nitrogen volatilization from bermudagrass treated with dairy manure. J. Prod. Agric. 10:266–271.

SAS Institute. 1990. SAS/STAT user's guide. Version 6. 4th ed. Vol. 1–2. SAS Inst., Cary, NC.

Sharpley, A.N., and A.D. Halvorson. 1994. The management of soil phosphorus availability and its impact on surface water quality. p. 7–90. *In* R. Lai and B.A. Stewart (ed.) Soil processes and water quality. Lewis Publ., Boca Raton, FL.

Sims, J.T., and D.C. Wolf. 1994. Poultry waste management: Agricultural and environmental issues. Adv. Agron. 52:1–83.

Stout, D.G., B. Brooke, J.W. Hall, and D.J. Thompson. 1997. Forage yield and quality from intercropped barley, annual ryegrass and different annual legumes. Grass Forage Sci. 52:298–308.

Torbert, H.A., D.W. Reeves, and R.L. Mulvaney. 1996. Winter legume cover crop benefits to corn: Rotation vs. fixed-nitrogen effects. Agron. J. 88:527–535.